COMPARISON BETWEEN SELF-COMPONENT AND STANDARD PROPELLERS IN CURRENT METER DISCHARGE MEASUREMENT

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ABSTRACT

During the official performance tests of two hydroelectric units, discharge has been measured by means of twenty-five currentmeters on a four arms frame placed in circular measuring section 4.65 m diameter and located in a straight portion of the tunnel with a straight length of 6 diameters upstream and 15 diameters downstream. The upstream disturbance was a smooth deviation of 5 degrees approx. while the downstream disturbance was a wide bend of 90 degrees approx.
Tests were performed using standard SIAP propellers. The results showed unexpected low discharge and flow pattern quite distorted in the central portion, consequently the turbine efficiency was higher than expected. The asymmetry index and the diameters comparison, required in ISO and IEC standard in order to verify the reliability of tests, were good. The fully developed flow index, on the contrary, was higher than the statistical limit 0.02. Presence of rotational components in the flow was supposed. As a consequence velocities and discharge could be under-estimated, especially in the central zone. We decided to change nineteen over the twenty-five propellers using OTT 45° self-component brass propellers and to repeat the tests.
The results of the second campaign show excellent flow profiles well matching with theory. The fully developed flow index is definitely lower than the statistical limit and the measured efficiency was in good accordance with the expected values.
In conclusion we confirm the use of fully developed flow index to identify problems in current meters measurements.

1. INTRODUCTION

In the performance tests of the hydraulic machinery the discharge always represents the most difficult variable to measure and its error plays the major role in evaluating the uncertainty of the turbine efficiency in comparison with the other hydraulic and electric parameters. More specifically, when currentmeters are used, the choice of the discharge measuring section is fundamental in order to obtain satisfactory results. Furthermore, even in observance of the international standards (IEC [1] and ISO [2]) the reliability of good tests is not guaranteed, since the upstream disturbances disappear in straight pipe lengths that are longer that the ones prescribed in the code.
The tests, described in this paper, compare the results obtained measuring the discharge in a big tunnel using standard and self-component propellers.

2. TEST PROCEDURE

During the official performance tests of two hydroelectric units, discharge has been measured by twenty-five current-meters installed on a four arms supporting frame placed in circular tunnel, 4.65 m diameter. The tunnel extends for 6558 m in the length from intake to surge tank, with slope variable between 0.12% and 2.4%. The entrance to tunnel is possible through a watertight door at progressive 6413 m and position of the discharge gauging section has been chosen approx. 18 m upstream, in straight stretch 21 diameters long. Six diameters upstream and fifteen diameters downstream were available. The upstream disturbance was a smooth deviation of 4.5 degrees, while the downstream disturbance was a wide bend of 88 degrees with 30 m radius of curvature. At 59 diameters upstream of discharge gauging section also exists a smooth change of the tunnel slope 1.08 degrees. A simplified scheme of the tunnel layout in the stretch interested by the discharge measurement is presented in Figure 1.

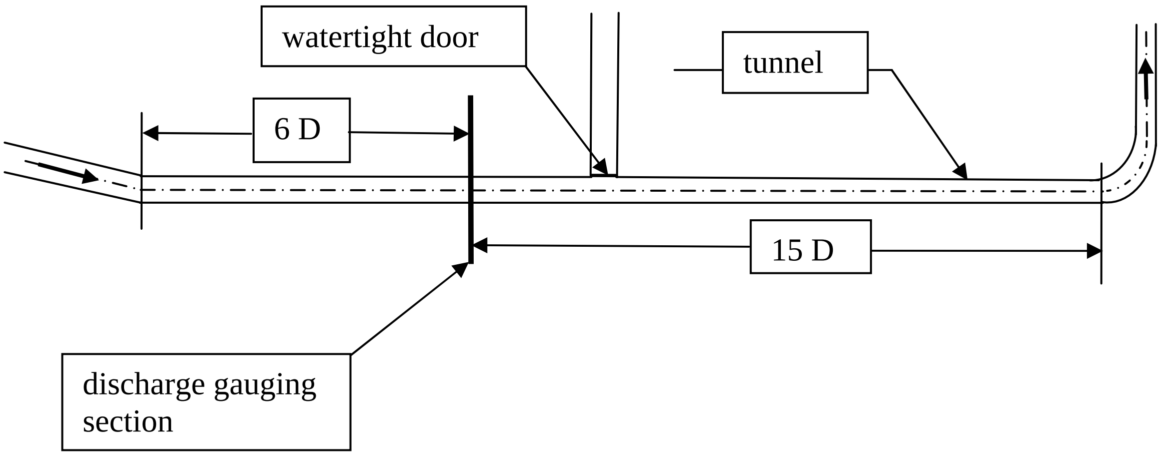

Figure 1 – Schematic layout of the tunnel and position of the discharge gauging section

The gauging section was almost compulsory. We considered that the upstream disturbances would not cause noticeable effects on the pattern of the flow field, as conversely it was definitely proved during the following testing. On the other hand the presence of the watertight door didn’t give the chance to move downstream the discharge gauging section in order to increase the upstream straight stretch.
Twenty-five currentmeters were installed on a four arms fixed supporting frame, at S. Andrews cross-disposed, in number of six currentmeters for each arm plus the one in the centre (Figure 2).

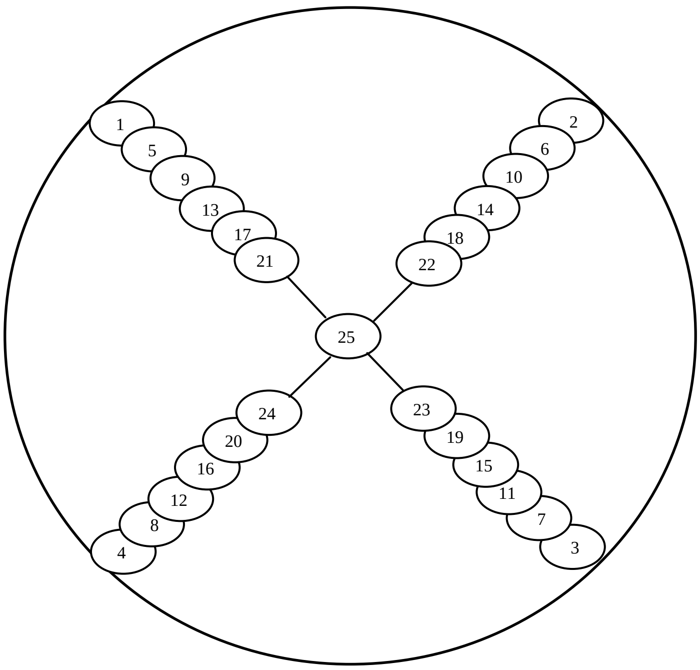

Figure 2 – Currentmeters arrangement on the frame

Each currentmeter was equipped with standard SIAP propeller 120 mm diameter, 0.25 m pitch, and the rotational speed indications were measured during 300 seconds and the value of the discharge has been computed using the cubic spline integration method as indicated in the ISO 3354.

3. TESTS CARRIED OUT WITH STANDARD PROPELLERS

The program of the official performance tests was to carry out measurements within the guaranteed range of the turbines between 5/10 and 10/10 of the maximum load. The first test, carried out on the second group at maximum load, showed an evident overestimation of the measured efficiency. The results were manifestly above to confidence range expected in this type of tests compared to the guaranteed values. A second test, carried out at 9/10 of the maximum load, confirmed the previous results, with a measured efficiency definitely higher (>2%) than the guarantees.
It was decided to investigate the cause of error. After having carefully checked the accuracy of all hydraulic and electric variables, the reason was focused in an underestimation of the discharge value. The picture of local velocities profiles, taken along the two diameters, showed an evident decrease of the velocity on the tunnel centre, mainly in the area of currentmeters in position number 21, 24 and 25 and slightly in the area of 17 and 20. The diagrams of the Figure 3, referring to maximum load test clearly illustrate this evidence.

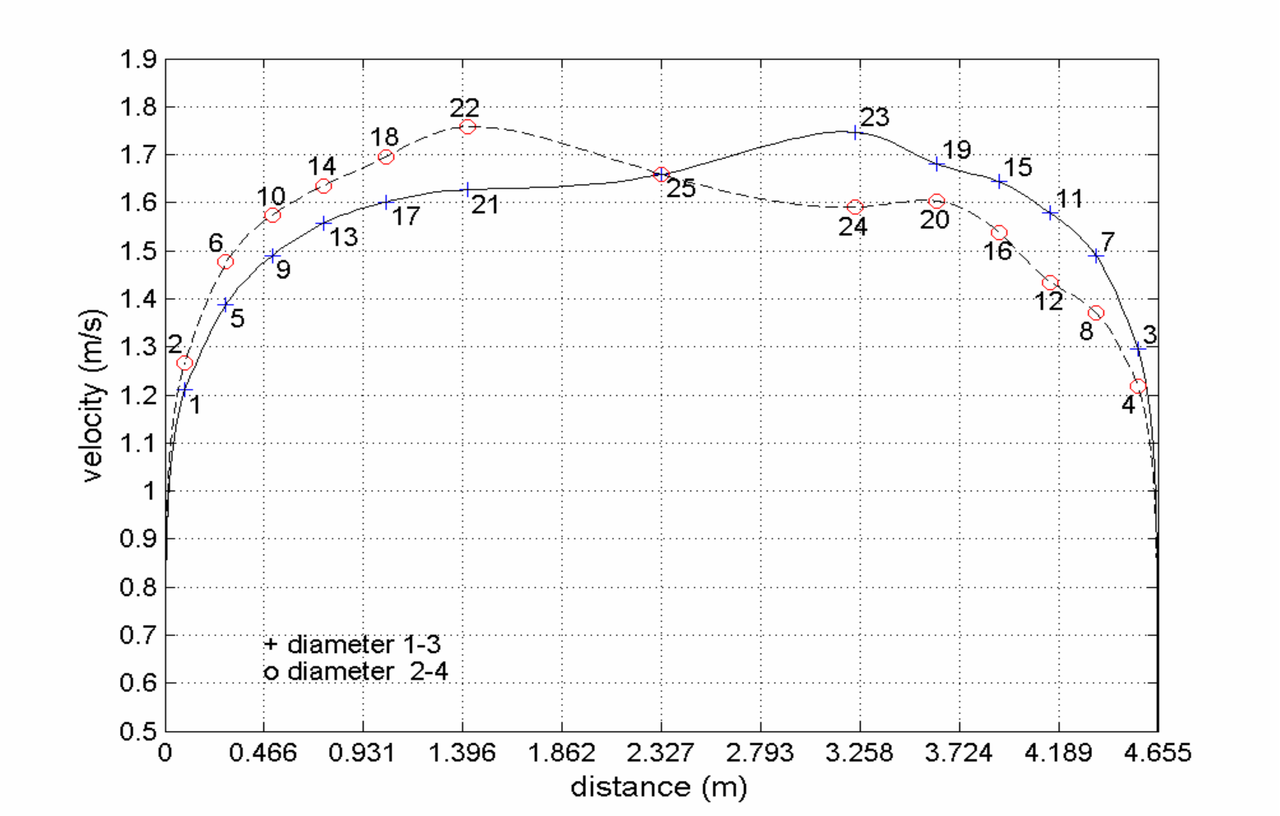

Figure 3 - Velocity distribution with standard propellers at maximum load

The diametral profiles were the evident sign of presence of distorted flow pattern mainly in the central portion, with maximum velocity shifted from the tunnel centre and located between arms number 2 and 3, corresponding to the ones at right side, observing the currentmeters supporting frame from upstream to downstream. This irregularity is highlighted by isovels showed in Figure 4, relating to maximum load test. The pattern of the isovels is identical for the test at 9/10.
In all examined cases, both the limit between the discharges calculated on the two diameters, as well as the asymmetry index as prescribed in the standards to be less or equal respectively to ±2% and 0.05, were fully observed.

The observance of these values should be a guarantee to consider satisfactory the discharge measurement, when the velocities assessment is made on two orthogonal diameters.
Actually the diameters difference between the discharges is resulted equal to ±0.38% of their mean and ±0.22% respectively for the tests 10/10 and 9/10 of the maximum load, while the asymmetry index is resulted equal to 0.037 e 0.040. Experience demonstrates, on the contrary, that the valuation methods proposed by standards to verify the acceptability of the discharge measurements in the circular pipes are necessary but not sufficient conditions.

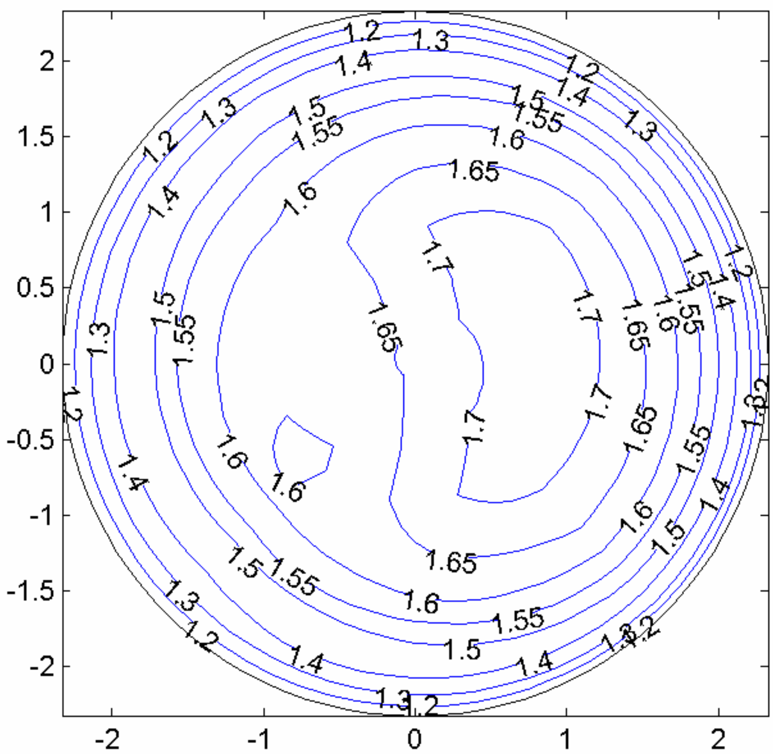

Figure 4 - Isovels with standard propellers at maximum load

4. INDEX OF FULLY DEVELOPED FLOW

A different parameter proposed by Grego [3] in the report presented at the meeting IGHEM in Kempten suggests the comparison between the adimentional velocities measured $v_i = V_i / V_m$ (with V_i averaged velocity at concentric circle radius r_i and $V_m = Q / S$) and the ones theoretic calculated for the same values of the adimentional radius $\frac{r_i}{R}$. The law of the velocity distribution in circular pipes has been developed following the theoretical studies carried out by Prof. E. Marchi [4] and experimental discharge measurements, carried out by ENEL in a wide population of hydroelectric power plants [5], considering only the ones obtained in fully developed flow conditions. The expression obtained is the following:

$$\frac{V}{V_m} = 1.1523 + 0.09211 \ln\left(1 - \frac{r}{R}\right) + 0.1858\Phi\left(\frac{r}{R}\right) \tag{1}$$

where V_m represents the average velocity in the pipe of R radius and r the distance of the local velocity from the pipe centre. The function $\Phi\left(\frac{r}{R}\right)$, tabled by Prof. Marchi, has been interpolated by a polynomial fourth degree and has the following expression:

$$\Phi\left(\frac{r}{R}\right) = -0.5530347\left(\frac{r}{R}\right)^4 + 1.6066064\left(\frac{r}{R}\right)^3 - 1.8782031\left(\frac{r}{R}\right)^2 + 0.6044168\left(\frac{r}{R}\right) + 0.0026893 \quad (2)$$

Here is reported the expression of the **Index fully developed flow** adopted by Grego in the report [3]:

$$Ifdf = \sqrt{\frac{1}{n}\sum_{i=0}^{i=n}\left[\left(\frac{V_i}{V_m}\right)_{meas.} - \left(\frac{V_i}{V_m}\right)_{teor.}\right]^2} \quad (3)$$

where n represents the number of concentric circles on which the local velocities are measured.
In the report [3] was proposed a value of the *Ifdf* less than 0.02 to consider satisfactory the discharge measurements in circular penstock. In the two tests carried out, conversely, the *Ifdf* proved to be quite higher than limit : equal to 0.028 e 0.033, respectively for the tests at 10/10 and 9/10 of the maximum load. These values confirm the presence of velocity not in the direction of the axial flow and its possible underestimation.
Moreover in the same report the author has recommended that a discharge measurement in circular pipe is satisfactory if the value of r/R, where the adimentional velocity assumes the unitary value, should be between 0.75 e 0.77. Values upper 0.77 indicate the presence of rotational flows and an underestimation of the discharge when using the standard propellers.
This is exactly the condition occurred in the described tests and therefore it has been decided to replace the standard SIAP propellers with self-component propellers OTT.

5. TESTS CARRIED OUT WITH SELF COMPONENT PROPELLERS

After the emptying of the tunnel it has been possible to ascertain that all the currentmeters were completely operational and no extraneous body was present on the propellers, particular care was taken in analysing the ones installed in the central zone where was evident the deficiency in the velocity diametral profiles. No evidence of suspended solid material was found which could have modified the proper behaviour of the currentmeters. All the propellers were perfectly clean and perfectly working. It was another indication that the error in the discharge measurement could be the flow field irregularity derived from the presence of patterns not parallel to tunnel axis and consequently not correctly measured by standard propellers.
Nineteen self component propellers being available at site, we choose of hold six standard propellers (three for each diameter) in the middle stretch of each arm in order to be able to highlight the velocity possible deficiency by using the pattern of the two diametral profiles obtained with the other ten self-component propellers.
Referring to the diameter 1-3 have not been replaced the standard propellers installed in the positions 13, 19 and 11, referring to the diameter 2-4 the ones in the positions 14, 20 and 12, as indicated in the Figure 2.
The velocity diametral profiles relating to maximum load test, drawn in the Figure 5, clearly show an increase of the velocity in the central zone and an underestimation in locations of standard propellers. The velocities, measured by these propellers, have been smoothly corrected in order to obtain a perfectly regular pattern of velocity diametral profile. The new profiles are drawn in Figure 6, where the positions of currentmeters object of correction have been highlighted. Such correction,

anyway, has involved an increase of the discharge of approximately 0.2 % in all the tests carried out between 5/10 and 10/10 of the maximum load.

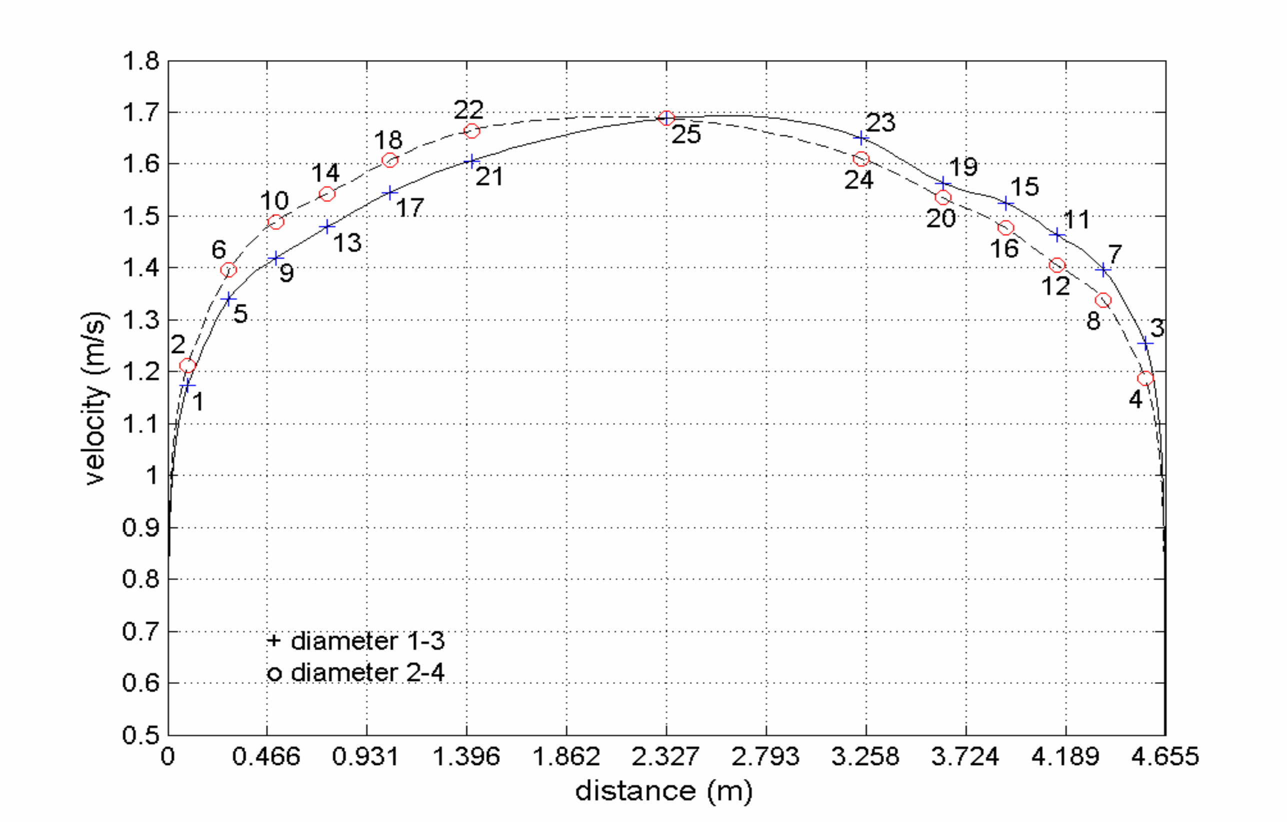

Figure 5 - Velocity distribution measured with six standard and nineteen self-component propellers at maximum load

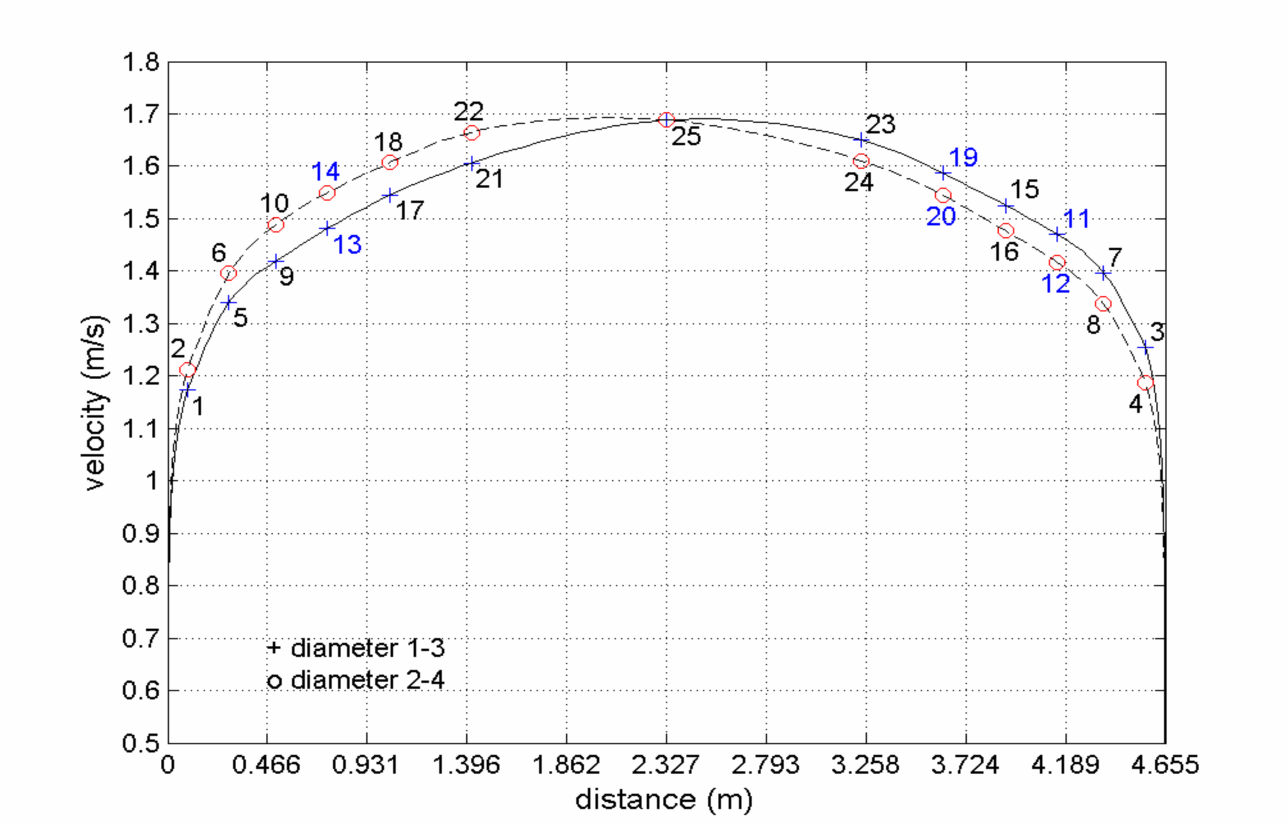

Figure 6 - Velocity distribution measured with six standard (corrected velocity) and nineteen self component propellers at maximum load

All tests performed using self-component propellers show that are widely fulfilled both conditions prescribed by the codes: the difference value between the discharges calculated on the two diameters being lower than 0.15 %, and as the asymmetry index lower than 0.03.
In this case also the **index of fully developed flow** is ranged between 0.003 e 0.006 in all the tests for both the groups which is definitely lower than the limit value suggested in [3]. The maximum value of the velocity occurs in the central area of the tunnel and the isovels, drawn in the Figure 7, are practically concentric and have a pattern very regular. As in previous diagrams, the test at maximum load has been illustrated, but results are definitely the same for all tests.

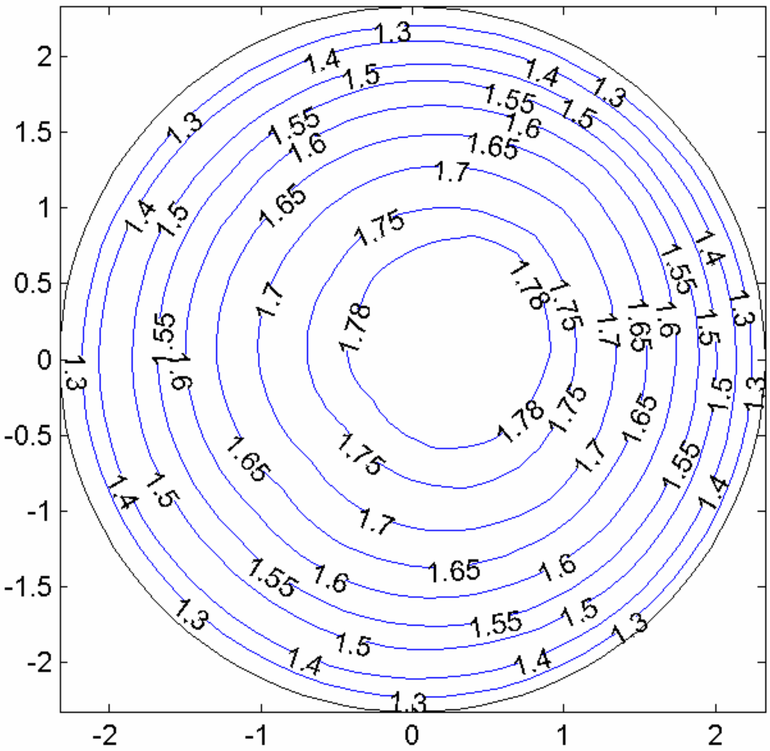

Figure 7 - Isovels with six standard propellers and nineteen self-component at maximum load

Using the formulas of the expressions (1) e (2) has been drawn the curve of the adimentional theoretic velocity versus adimentional radius and compared with experimental data obtained from measurements both by means of standard and self-component propellers.
The experimental data of the velocity values obtained as average on four radiuses for each concentric circle and as the single velocity value for the central have been interpolated using cubic spline and the Von Karman law near the wall. The first tests, carried out using only standard propellers, display a marked difference between the experimental data and the theoretic, particularly in the central zone and the value of the adimentional radius r/R where V=Vm is higher than 0.77. In the second run of tests, carried out using nineteen self-component propellers, the distribution curve of the adimentional velocity practically overlaps the one theoretic. This confirms that the local velocity also with rotational flow, particularly evident in the central zone, has been correctly measured. The Figure 8 shows, by way of illustration, always the test at maximum load, but the results are equal also for all the tests at partial load.

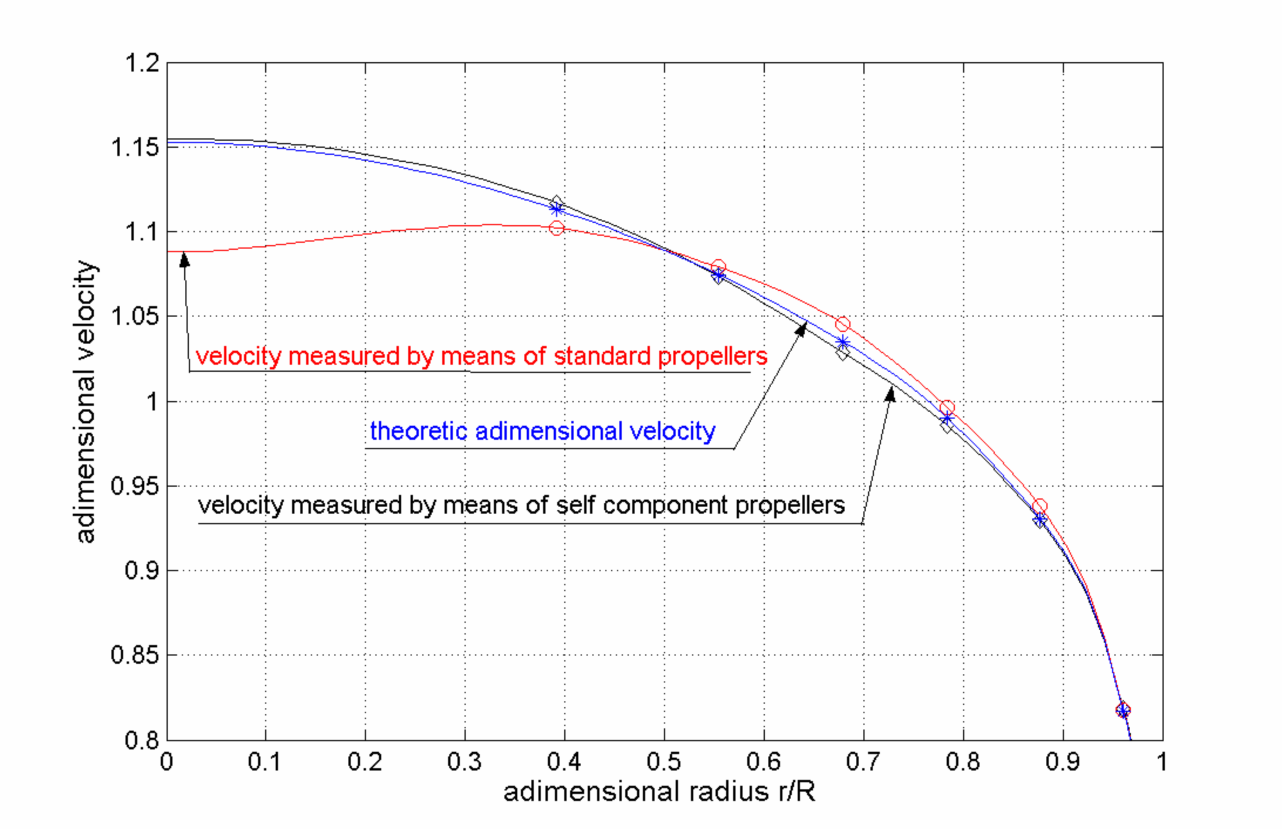

Figure 8 – Adimentional velocity distribution versus adimentional radius

6. CONCLUSION

Previous papers presented by authors in both ICMG and IGHEM and experience show that the criteria prescribed in the code to verify the reliability of discharge measurements by means of currentmeters are generally necessary but **not sufficient conditions** to obtain good results. This test case also confirms this point.

During the official performance tests of two hydroelectric units, discharge has been measured by twenty-five currentmeters installed on a four arms supporting frame placed in circular tunnel, 4.65 m diameter, in a section where the only remarkable disturbance was a smooth deviation of only 4.5° of the tunnel axis located 6 diameters upstream the gauging section.

A first set of tests performed by using standard propellers show a remarkable underestimation of discharge while the criteria, prescribed in the code to verify the reliability of discharge measurements, were fulfilled.

On the contrary, a second set of tests performed by using self-component propellers gave good results. The only detection of the problems occurring during the first set of tests was the value of the **index of fully developed flow** a new parameter proposed by Grego [3] in the report presented at the meeting IGHEM in Kempten. The value of the index in the first set of tests was much higher than the limit of 0.02. In case of wide rotational components standard propellers may not measure the real axial velocity and the index of fully developed flow clearly detects this condition.

In the second set of tests velocity profiles and isovels curves were much more regular, remarkably different from the previous set and also the **index of fully developed flow** was within the limits.

In this test case the error due to usage of standard propellers has been evaluated in the range of –2% as calculated on the basis of comparisons between the two sets of tests.

In conclusion, whenever the velocity values and the absence of suspension material allow, is worth to use self-component propeller, if a presence of rotational flow is expected as consequence of even little changes in the upstream pipe.

Should the international codes integrate the reliability criteria in order to have necessary and sufficient conditions to analyse results. The **index of fully developed flow** (limit value 0.02) and the calculation of the adimentional radius r/R where V=Vm (good value 0.76) demonstrate to be necessary and sufficient parameters to detect distorted flow conditions.

7. REFERENCES

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